

Prediction of Crack Locations using Non Destructive Tests

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Abstract

Objectives: In this paper non destructive tests are used to find the location of multiple cracks in the cantilever beam. **Methods/Analysis:** The impact echo test along with Ultrasonic Pulse Velocity (UPV) test is used to find the crack locations. These tests are conducted on cantilever beam having two cracks at different positions. The frequency spectrum is recorded from the impact echo test. While the ultrasonic pulse time is recorded from ultrasonic pulse velocity test. A MATLAB based code is used to find out the dominant frequency of the sound signals corresponding to each impact echo test. The ultrasonic pulse velocities are calculated from the travel time and the distance between the transducers. **Findings:** It was found that the frequency values are increasing when the cracks move away from the fixed end of the cantilever beam since the frequency ratio increases when the distance of the crack increases from fixed end (based on Equation 3). Ultrasonic pulse velocity also increases since the distance between the transducers of the UPV equipment decreases when the location of crack changes. **Applications/Improvements:** From the values of frequency and ultrasonic pulse velocity, mathematical expressions of crack location are developed. The developed expressions are tested on the cantilever beam to find the crack locations in a laboratory model.

Keywords: Crack Location, Impact Echo Test, MATLAB, Multiple Cracks, Non Destructive Tests, Ultrasonic Pulse Velocity Test

1. Introduction

Vibration based methods are commonly used to predict the presence and location of the cracks in structures. In majority of the vibration based methods, crack location and crack depth of a structure are determined by using the modal parameters such as frequency. The values of frequency depend on the crack size, crack depth and crack position in any structure. So the variation these parameters will give considerable change in the frequency response. For conducting the vibration based experiments to find the location and depth of the crack beam structures are commonly used. Metal beams are more suitable for this because of the homogeneity and isotropic properties. In this paper, a frequency based test and ultrasonic based test are described. That are impact echo test and ultrasonic pulse velocity test respectively. This paper mainly focuses on the determination of location of two transverse cracks on a cantilever beam using the above tests.

Presented¹ the vibration analysis on a cantilever beam having single crack. They have performed experiments to get the frequency change with respect to crack location and crack depth on cantilever beam. They concluded that, under no load the frequency decreases with crack depth increases. While frequency increases when the crack location moves away from the fixed end. From the study of vibration analysis conducted on simply supported beam by², it can be seen that when crack moves from the support to the midspan of the simply supported beam the lowest fundamental frequencies decrease. The cracks which are at symmetric positions of the beam, the lowest fundamental frequencies are almost equal. Demonstrated³ theoretical and software analysis of structures. They are concluded that the natural frequency varies with both crack depth and crack location. These changes are observed at the area of crack location. Other than the experiment analysis, software analysis also significant to compare the result with theoretical or experimental

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studies. Presented⁴ the analysis of a cracked cantilever beam using finite element method. In their study, they obtained that when crack depth increases the value of natural frequency of the beam decreases. Presented⁵ an experimental study of the crack detection for cantilever beams. Their study reveals that, when the position of crack location moves from the fixed end of the cantilever the vibration amplitude at higher natural frequency will increase but amplitude at lower natural frequency will decrease. Studied⁶ the significant benefits of vibration based method for the crack prediction over other regular non destructive tests. They presented modeling of the crack as a torsional spring and the crack location was predicted successfully. In their method an error of 4% was occurred in finding crack location and crack size. Used⁷ the finite element based analysis to detect the crack in cantilever beam. They presented the effects of crack on the first three modes of vibrating cantilever beams. At the end of their work, they have demonstrated crack identification technique by using frequency contours.

Ultrasound method is an NDT method for concrete and other materials. In this paper, Ultrasonic Pulse Velocity (UPV) is conducted on aluminium beams. The variation of ultrasonic waves depends on the type of material, homogeneity, presence of defect etc. Mentioned⁸ that ultrasound won't transmit through the concrete linearly. Because of the presence of uneven rough stones and mortar in concrete, the ultrasound waves will undergo for reflection and refraction. But in the homogeneous materials like metals, this many disturbances for sound wave will not be there. If the material is stressed or cracked those will affect the speed of sound waves. Used⁹ the ultrasonic signal characteristics for the yield detection in steel structures. They have plotted the relative change in the sound wave speed with strain and stress. Presented¹⁰ the ultrasonic surface wave characterization using Rayleigh waves.

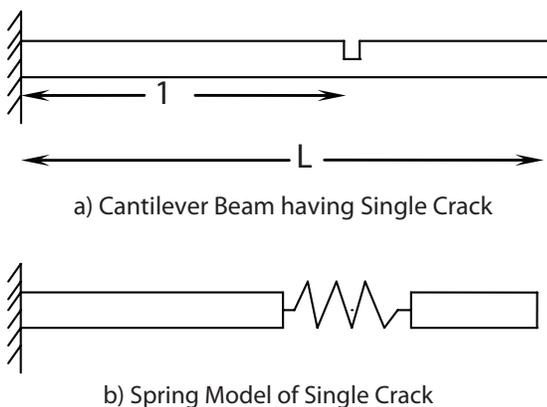


Figure 1. Cantilever beam having single crack

He could detect and predict the surface crack in different metal component structures. Presented¹¹ a pulsed laser ultrasound method to detect the crack in aluminium sheets and concluded that the laser generated lamb waves can clearly propagate around the cracks. Proposed a¹² method based on the application of Hilbert transform to detect flaw characteristics from the ultrasonic testing. Stainless steel and carbon steel are considered for the method.

2. Theoretical Study of Frequency and Crack Location

The crack on the cantilever beam can be modeled by a spring of stiffness K_x (Figure 1). Have¹³ mentioned the mathematical expression for finding the change in frequency at any fundamental mode. That is given by,

$$\frac{\Delta f}{f} = \sin^2\left(\frac{n\pi l}{2L}\right) \cdot \frac{EI}{K_x L} = \tag{1}$$

Stiffness of spring can be calculated as,

$$K_x = \frac{EI}{5.346h \cdot f(a/h)} \tag{2}$$

Now the change in frequency becomes,

$$\frac{\Delta f}{f} = \sin^2\left(\frac{n\pi l}{2L}\right) \cdot \frac{5.346h \cdot f(a/h)}{L} \tag{3}$$

Where EI = Flexural stiffness

l = Distance of crack from the fixed end of the cantilever

L = Length of the cantilever

a = Size of crack

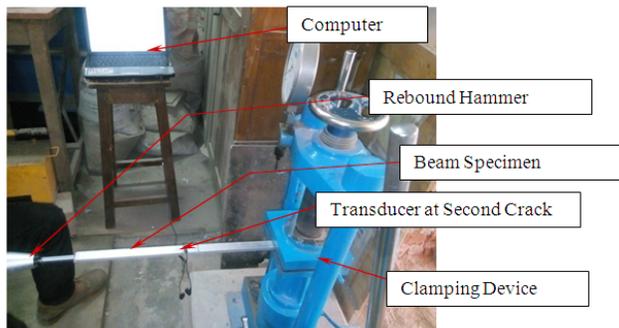
h = Height of crack

Value of the function $f(a/h)$ depends on the crack size and crack height.

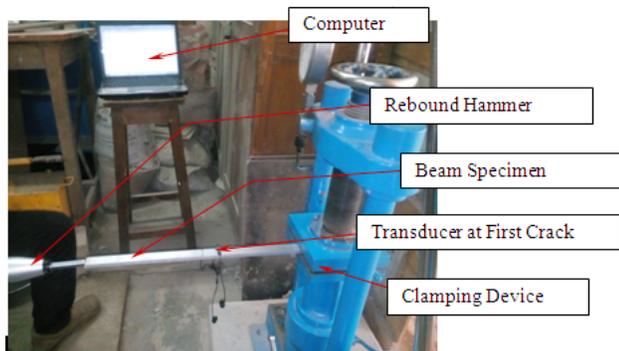
3. Experimental Setup

The experiment consists of impact echo test and ultrasonic pulse velocity test. Both these tests are conducted on cantilever beam of aluminium having two cracks at its surface. Aluminum beams of 250 x 100 mm cross section and 500 mm length are used. Transverse cracks of 2mm size and 3mm depth at first location and 2mm size and 2mm depth at second location are made on the beam surface from the fixed end of the cantilever. For impact echo test, a transducer is attached on the beam surface at first

crack location and the frequency spectrum is recorded. Then, the transducer kept at second crack location and the frequency spectrum is recorded. All Impacts are given at the free end of the cantilever using a rebound hammer. For ultrasonic pulse velocity test, the transmitter of the UPV apparatus is placed at the free end of the cantilever and receiver is placed at the different crack locations. The ultrasonic pulse times are recorded. The above procedure is repeated for the cantilever beams having two cracks at different locations. The experimental arrangements are shown in Figures 2 and 3.

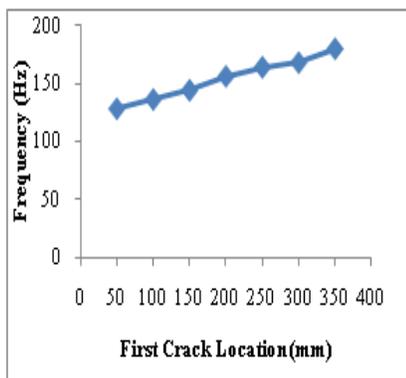


a) Transducer Kept at First Crack

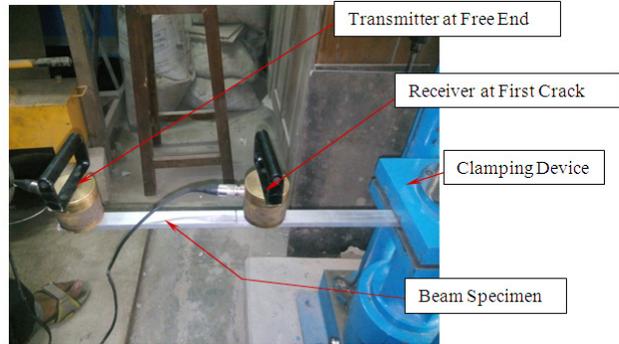


b) Transducer Kept at Second Crack

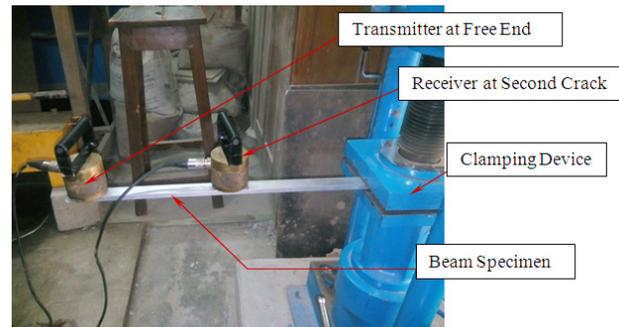
Figure 2. Impact echo test on cantilever beam having two cracks



a) First Crack



a) Receiver Kept at First Crack

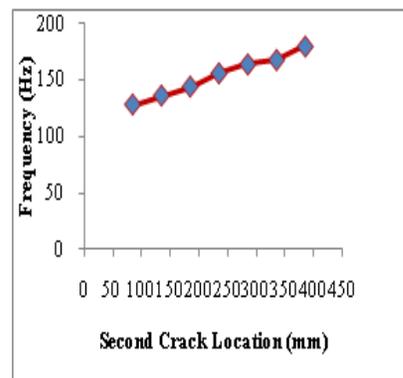


b) Receiver Kept at Second Crack

Figure 3. Ultrasonic pulse velocity test on cantilever beam having two cracks

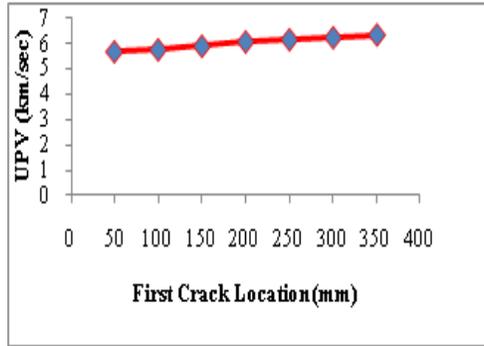
4. Result and Discussion

From the values got from the experiment, graphs are plotted between frequency and crack location, ultrasonic pulse velocity and crack location. Those plots are shown in Figure 4 and 5. Finally mathematical expressions were developed to find the locations of the two cracks in the cantilever beam using frequency and ultrasonic pulse velocity.

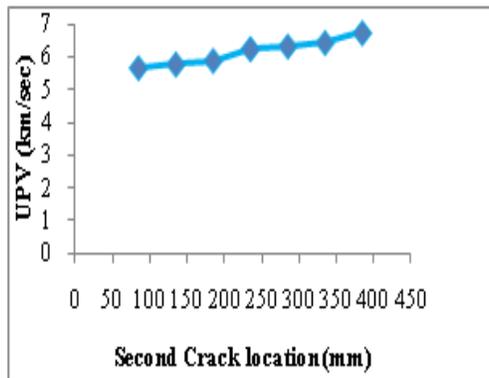


b) Second Crack

Figure 4. Typical frequency vs. crack location diagrams for two cracks on the cantilever beam



a) First Crack



b) Second Crack

Figure 5. Typical UPV vs. crack location diagrams for two cracks on the cantilever beam

From Figure 4, it is noted that the frequency values of the beam increase when the crack location shifts away from the fixed end. This has been verified using Equation 3. When the crack size and crack depth are constant of the same cantilever beam, obviously can clarify that the frequency ratio increases when crack location shifts from the fixed end. Have⁵ presented that the stiffness value of the cantilever beam increases when crack location goes away from the fixed end. So it can say that frequency also will increase with crack location goes away from fixed end since frequency and stiffness are directly proportional. Ultrasonic pulse velocity response is shown in Figure 5. It is observed that, there is a slight increase in UPV for both first and second crack location when cracks shift from the fixed end.

4.1 Mathematical Expression to Calculate the Crack Location

Mathematical equations were developed using linear regression analysis from the values of frequency, ultrasonic pulse velocity. Using these equations, by knowing

the frequency and ultrasonic velocity we can predict the locations of the cracks on the cantilever beam. Equation 4 and 5 show the expressions for calculating the first and second crack location on the cantilever beam respectively. Tables 1 and 2 show the actual and predicted values of crack locations on the cantilever beam using the Equation 4 and 5. The bar diagrams of the same are shown in Figure 6.

$$y_1 = 8.38f + 179.74v - 2.77 \tag{4}$$

$$y_2 = 10.22f + 216.3v - 1.51 \tag{5}$$

Where y_1 = Location of First Crack from the fixed end in mm

y_2 = Location of First Crack from the fixed end in mm

f = Frequency in Hz

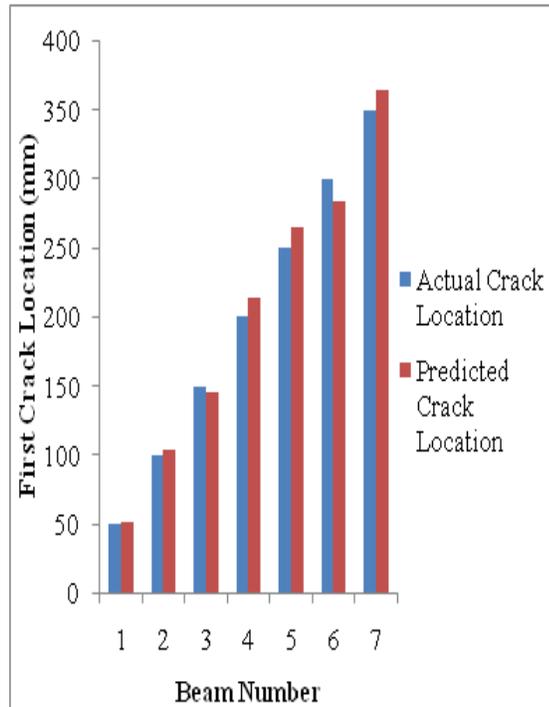
v = Ultrasonic Pulse Velocity in km/sec

Table 1. Actual and predicted location of the first crack on the cantilever beam

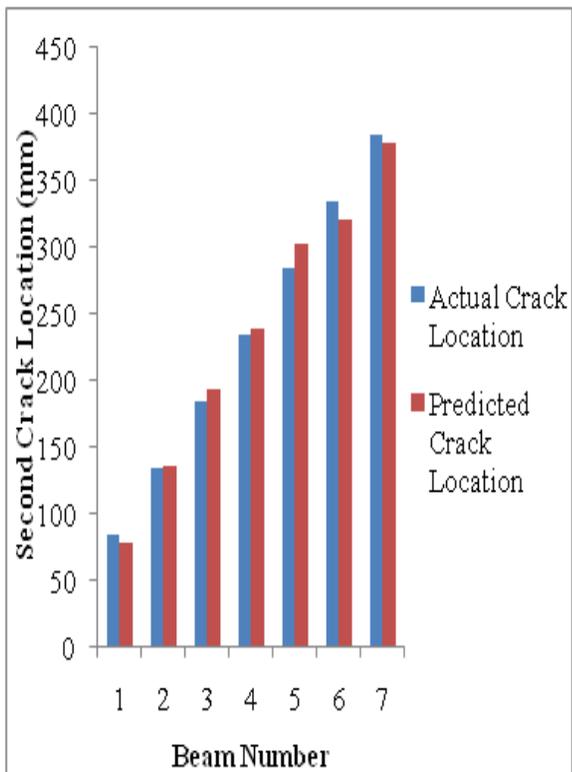
Actual First Crack Location (mm)	Frequency (Hz)	UPV (km/sec)	Predicted First Crack Location (mm)	% error
50	128	5.67	50.74	1.49
100	136	5.75	103.41	3.40
150	144	5.89	145.28	3.15
200	156	6.07	213.49	6.74
250	164	6.16	264.35	5.74
300	168	6.24	283.49	5.50
350	180	6.35	364.28	4.08

Table 2. Actual and predicted location of the second crack on the cantilever beam

Actual Second Crack Location (mm)	Frequency (Hz)	UPV (km/sec)	Predicted Second Crack Location (mm)	% error
85	128	5.68	78.07	8.16
135	136	5.79	136.03	0.77
185	144	5.9	194	4.86
235	156	6.26	238.77	1.61
285	164	6.34	303.23	6.40
335	168	6.45	320.32	4.38
385	180	6.75	378.07	1.80



a) First Crack



b) Second Crack

Figure 6. Actual crack location comparison with the predicted crack location of the cantilever beam

5. Summary and Conclusion

The crack location algorithms are proposed based on frequency and ultrasonic pulse velocity values from the linear regression analysis. By knowing the values of frequency and ultrasonic pulse velocity, it is possible to determine the unknown crack locations in the cantilever beam. In this paper, two different cracks at certain interval were predicted with its locations. The predicted crack locations were compared to the actual crack locations on cantilever beam model. The crack locations were found to be very close to the actual crack locations.

6. References

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